AUSTRALASIAN RAILWAY ASSOCIATION

rps MAKING COMPLEX EASY

The Renaissance of Light Rail

Research Paper

APRIL 2021

Contents

Executive Summary

RPS is pleased to partner with the Australasian Railway Association (ARA) to develop a research paper reflecting on the role light rail has played in Australian society.

The research also identifies that a new appreciation for what light rail delivers has led to a renaissance of light rail projects across the country. The combination of urban regeneration, amenity and reliability has seen light rail return to Australian cities to help revitalise CBDs and attract investment. This paper defines a framework to demonstrate the relative benefits and limitations of transport mode choice, outline the role light rail can play and consider what makes light rail projects successful. We then look at light rail projects currently being proposed and how these align with the framework.

Light rail has roots deep in Australian history dating back to 1879 when Sydney had one of the largest tram networks in the world. Australian cities removed tram systems as the growth in private motor vehicle ownership took off in the 1970s and light rail was considered an impediment to the movement of private vehicles. By the early 2010s as road congestion worsened, many cities globally have looked to revaluate its public transport options. A comparison of several contemporary and emerging transport technologies including bus rapid transit (BRT), trackless trams and light rail was undertaken to establish the global context, and determine the respective benefits and challenges associated with the use of each mode.

The review indicated that bus, BRT, and its emerging technology hybrids can be successfully adapted rapidly and flexibly deployed to address a range of transport challenges around the world. Trackless tram technologies have had limited use globally. The emergent trackless trams being considered in the Australian context draw on more contemporary high speed rail technology and is currently limited to only two cities in China. It therefore remains a largely unproven mode of transport.

Light rail with in-ground steel guide rail systems has **comparatively greater land use and placemaking potential and provides greater capacity to move passengers** than buses. Light rail also provides a more flexible solution than heavy rail or metro systems which are highly complex, require significant investment and have lengthy lead times to deliver and commission.

Through consolidating the insights gained from the modal comparison, along with a review of several local and international case studies, RPS and ARA have developed a transport planning decision-making framework that uses a Red-Amber-Green (RAG) ranking against key decision-making criteria (refer Figure E-1) to help determine the most appropriate modal choice depending on a project's context and the outcomes it is attempting to achieve.

The framework assesses each mode choice against the following considerations:

Urban renewal/land value uplift - ability to generate some form of land value and density uplift along the corridor it is servicing

Amenity - ability to provide amenity, both at the stop and during the journey (included ride smoothness, accessibility, legibility, real time information, announcements, seating)

Stop frequency - total catchment served, with a higher number of stops per kilometre resulting in more of the population being within walking distance of public transport

Reliability/proven technology - ability to provide on time services via a proven mode of transport

Patronage - ability to move a large number of people easily and efficiently through frequency of services or length/size of vehicle

Service frequency - ability to increase or decrease service frequency easily

Travel time saving - ability to improve travel times across multiple different types of trips

Delivery constraints - the complexity of delivery and affordability of both fixed infrastructure and fleet

Flexibility in routes - ability to move or change routes easily

Budget considerations have not been accounted for in the framework as they are unique to each project and should be weighed against the relative benefits and objectives of each project.

The research found that:

1. Buses and advancing bus technologies (such as electric BRTs, trolleybuses and electrically/optically guided bus systems) are well suited to corridors that are experiencing changing travel patterns, require stop relocation and route flexibility.
2. BRT and other protected vehicles are well suited to corridors with high patronage demand throughout a movement corridor.
3. Light Rail is well suited to transport projects that seek to help catalyse and coordinate land use change whilst being capable to meet high patronage demand throughout a movement corridor.
4. Heavy Rail is well suited when you need to move high numbers of passengers across larger distances and catalyse key employment and residential centres.

Australasian Rail Association / Renaissance of Light Rail Report

Below is a summary of the performance of each mode against the identified key decision making criteria.

While it is clear that light rail is not the solution to every transport problem, light rail does have an important role to play in any integrated transport network and has many strengths. Critically, where there are broader land use, amenity and urban regeneration outcomes that are needed throughout a corridor, light rail is well placed to deliver these.

To further accelerate light rail development and support its ongoing success in our cities, the paper poses the following policy recommendations for government consideration to support the next wave of light rail investment and delivery.

Recommendation 1: Refine the policy framework to assess the broader benefits light rail projects deliver

- Recommendation 1.1: Government(s) reform the business case and appraisal approach to better consider land use, urban renewal and 'place' outcomes alongside conventional transport benefits. This includes not only developing consistent approaches to measuring these benefits but also recognising the contribution that transport projects have to the urban realm and creation of new public places.
- Recommendation 1.2: Optimisation of the light rail network (through signal priority) is considered during the business case concept design development phase to establish a more accurate portrayal of timetable performance throughout the day and optimise the service delivery of the network.
- Recommendation 1.3: Stakeholder engagement during the planning and development phases of a light rail project transition from best-practice to a government assurance requirement (e.g. as co-sponsors of a business case).

	Patronage	Delivery constraints	Reliability	Flexibility in routes	Urban renewal and value uplift	Travel time savings	Stop frequency	Service frequency	Amenity
Bus	Is not well placed	Delivers well	Is not well placed	Delivers well	Is not well placed	Is not well placed	Delivers well	Partially meets	Partially meets
BRT (on road)	Partially meets	Is not well placed	Partially meets	Partially meets	Is not well placed	Partially meets	Delivers well	Delivers well	Partially meets
Light Rail	Delivers well	Partially meets	Delivers well	Is not well placed	Delivers well	Delivers well	Delivers well	Delivers well	Delivers well
Heavy Rail	Delivers well	Is not well placed	Delivers well	Is not well placed	Delivers well	Delivers well	Is not well placed	Partially meets	Delivers well

Key

● (dark) Is not well placed to meet this criterion ● (grey) Partially meets this criterion ● (green) Delivers well against this criterion

Figure 1: Decision Making Framework

Note, trackless trams have not been included as this is an emerging technology that is unproven in Australian conditions. This is discussed further in section 2.1.3.

Australasian Rail Association / Renaissance of Light Rail Report

Recommendation 2: Develop a co-ordinated funding approach

- Recommendation 2.1: To reduce a project's overall cost to government(s), earlier action should be taken to capitalise on value-capture opportunities that exist well before construction commences (i.e. during the planning and development phase). An example of this could include coordinated corridor protection activities before a project is announced.
- Recommendation 2.2: Government(s) consider a contribution obligation for landowners following rezoning to provide early and adequate funding for land. Equally government(s) could also consider the introduction of a transport levy that provides a balanced approach to fund local projects using ratepayer contributions.
- Recommendation 2.3: Where possible, seek council stakeholders as sponsors/owners of light rail business cases.
- Recommendation 2.4: To minimise funding delays, Federal Government to identify what it requires to support investment in light rail projects.

Recommendation 3: Reduce delivery phase risks through an improved risk sharing approach

- Recommendation 3.1: Where there are potential significant construction related risks, a greater level of investigation should be undertaken as part of the project development phase to provide a more accurate representation of predicted project costs. Furthermore, in cases where this is not possible, a collaborative procurement approach where risks are appropriately shared between the contractor and government should be established (e.g. Alliance model).
- Recommendation 3.2: Utilities have posed a large risk across multiple light rail projects. It is recommended that this risk is specifically targeted in early development phases of the project, with greater knowledge sharing and transparency between utility providers and light rail proponents (including sharing of utility locations and ensuring new utilities are appropriately mapped), so that this risk is proactively mitigated.

It is important to acknowledge that although there are challenges associated with ensuring the appropriate level of light rail network integration is achieved (e.g. links to mass transit, buses etc.), these can typically be overcome by articulating the "do nothing" case, establishing community consensus for transport and place planning outcomes, early stakeholder engagement, consideration of new and emerging technologies, and policy mechanisms to optimise outcomes. Furthermore, when the right ingredients are present for light rail, the significant economic, social and environmental benefits are likely to more than offset any of the potential costs and challenges.

Introduction

1.1 Context

With over two thirds of Australians currently living in our capital cities[1], increasing urbanisation is putting greater pressure on our roads, the environment and quality of life.

The fundamental urban challenge of the 21st century is making our cities sustainable and inclusive places to live, work and play. To meet this challenge, Australia needs to accelerate improvements to our existing public transport networks through the integration of additional transport options.

Choosing the appropriate transport mode (e.g. bus, bus rapid transit (BRT), trackless tram, light rail or heavy rail) and the scale of infrastructure response should depend on the problem to be solved, or equally, the opportunity or benefit that can be realised. While each transport option has a very important role to play in the modal hierarchy, the focus needs to be on choosing the right mode in the appropriate context.

Light rail presents an unrivalled opportunity for more sustainable urban lifestyles as it provides greater mobility and accessibility for the community. It is most successful when used to catalyse land use change through facilitating urban realm improvements and place-making outcomes.

This is achieved by light rail's ability to provide high frequency, 'turn-up-and-go' connections between a range of mixed use, education, health, residential and special events precincts in a way that is quiet, safe and sustainable whilst the tracks in the ground is proven to provide certainty that supports urban development and densification.

We can see the investments made in light rail already delivering on this urban regeneration. In Canberra, house prices in proximity to light rail stops increased by between 27% and 39% (against a territory average of 17%), while simultaneously allowing for the renewal of aged social housing stock and catering for the projected population increases[2].

It is a similar story on the Gold Coast, with underlying property values increasing by as much as 30% around proposed station locations[3]. This uplift provides the catalyst for the urban regeneration often associated with light rail projects. In many ways light rail is becoming the transport solution to a land use problem and should considered to be a key component of any transport network, particularly as governments around Australia increase its focus on place based planning and outcomes.

[1] Australian Bureau of Statistics, 2017, Census reveals two thirds of our population live in Australia's capital cities, https://www.abs.gov.au/ausstats/abs@.nsf/lookup/Media%20Release10, accessed 22/12/20
[2] https://www.act.gov.au/__data/assets/pdf_file/0007/1544938/City-to-Gungahlin-Light-Rail-Benefits-Realisation-Snapshot-May-2020.pdf accessed 5 May 2021.
[3] https://news.griffith.edu.au/2017/05/30/research-finds-gold-coast-light-rail-property-value-sweet-spot/ accessed in 5 May 2021.

1.2 Scope

RPS has been engaged by the ARA to provide a research paper that details the renaissance of light rail locally and globally and establishes a transport planning decision-making framework to consistently determine the appropriate modal choice, whether bus, BRT, light rail or heavy rail and provide policy recommendations to support the next wave of light rail delivery.

The report structure is detailed below:

Section 2
Modal comparison

Comparison of light rail to other typical transport solutions (Bus/BRT, trackless trams).

Section 3
Light Rail Deep Dive

Articulating the proven benefits and challenges of light rail within a wider transport network context including successes achieved through recent projects[4].

Section 4
Decision-making framework and policy recommendations

Establishment of a framework to support a consistent approach to future transport planning decision-making, and policy recommendations to support the next wave of light rail investments.

[4] Local and international project examples include Mecca Light Rail (Saudi Arabia), Parramatta Light Rail Stage 1 (Australia), Newcastle Light Rail (Australia), Yarra Trams (Australia), Canberra Light Rail Stage 1 (Australia), Waterloo Light Rail (Canada) and Luas Light Rail (Ireland).

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2.

Comparing Typical Transport Modes

This section compares the strengths and weaknesses of the construction, operational and maintenance requirements for BRT, trackless trams and conventional light rail.

2.1 Modal Context

2.1.1 Bus Rapid Transit

BRT is a high-quality bus-based transit system that delivers fast, comfortable, and under the right circumstances, cost-effective services[5].

It typically does this through the provision of dedicated lanes, with busways and iconic stations usually aligned to the centre of the road, off-board fare collection, tram-like all door boarding experience, and fast and frequent operations. However, while BRT and bus routes are more flexible than transport modes with permanent infrastructure (like light rail and heavy rail), the network flexibility means they do not encourage population growth or urban renewal outcomes in the same ways as light rail and heavy rail do.

There are 176 cities across six continents that have implemented BRT systems, accounting for 5,308km of BRT lanes globally. Around 61% of the total passenger movements occur in Latin America, which has the most cities with BRT systems[6].

BRTs offer highly flexible service parameters and while the contemporary practice is to construct exclusive use corridors, they are a flexible solution that can be adapted to common (shared) road conditions, exclusive corridors (as depicted in Figure 1) and separated time of day protected lanes. Additional services can be added along existing routes, with minimal infrastructure upgrades (e.g. does not require power network upgrades).

Figure 2: BRT network in Quito, Ecuador[7]

There are varying BRT systems in several Australian capital cities, including the Brisbane busways system, the Adelaide O-Bahn Busway, the Sydney to Liverpool Transitway and the Melbourne Smart Bus System[8]. The newest system will be Brisbane Metro in Queensland, which is expected to be completed in 2023.

[5] BRT costs can become significant if the project requires large stop areas, overtaking lanes, expanded bus interchange etc.
[6] EMBARQ – The WRI Center for Sustainable Transport, 2016, Global BRT Data — Worldwide and Key indicators per region, https://brtdata.org/, accessed 18/01/21.
[7] Institute for Transportation & Development Policy, What is BRT?, https://www.itdp.org/library/standards-and-guides/the-bus-rapid-transit-standard/what-is-brt/#:~:text=-Bus%20Rapid%20Transit%20(BRT)%20is,services%20at%20metro%2Dlevel%20capacities.&text=Because%20BRT%20contains%20features%20similar,faster%20than%20regular%20bus%20services., accessed 18/01/21.
[8] OzeBus, What is Bus Rapid Transit?, http://bic.asn.au/information-for-moving-people/bus-rapid-transit#:~:text=BRT%20Systems%20in%20Australia,the%20Melbourne%20Smart%20Bus%20System., accessed 18/01/21.

Practical Example: Brisbane Metro, Queensland

The new Brisbane Metro will support a mixed vehicle environment as a mechanism to deliver a BRT system on the existing 21 km busway infrastructure. The project will provide better reliability, frequency and capacity on services as a result of the new vehicles and bus network re-design works being undertaken.

While the Metro's 25 metre bi-articulated vehicles are a smaller configuration than trackless trams or light rail vehicles (refer Figure 2), as they are a new vehicle technology in Australia, legislative amendments are being required to support their use on our roads.

Figure 3: Brisbane Metro

Brisbane Metro highlights that there are different types of vehicle configurations that can support BRT; however, legislative amendments may be required depending on the vehicle selected to deliver the service.

Source: [9, 10, 11]

[9] Railway Technology, Brisbane Metro, Australia, https://www.railway-technology.com/projects/brisbane-metro/#:~:text=Brisbane%20Metro%20is%20a%20new%20rapid%20transit%20system%20that%20has,in%20Brisbane%2C%20Queensland%2C%20Australia.&text=Initial%20construction%20of%20the%20Brisbane,scheduled%20for%20completion%20in%202023, accessed 18/01/21.
[10] Brisbane City Council, 2021, Brisbane Metro vehicle, https://www.brisbane.qld.gov.au/traffic-and-transport/public-transport/brisbane-metro/brisbane-metro-vehicle, accessed 29/01/21.
[11] Brisbane City Council, 2017, Brisbane Metro – Business Case Key Findings, https://www.brisbane.qld.gov.au/sites/default/files/20170530_-_brisbane_metro_business_case_key_findings_may_2017.pdf, accessed 29/01/21.

2.1.2 Trolleybuses and Electric Bus Rapid Transit

Trackless trams have been around since early in the 20th Century. Colloquially known as Trolleybuses, they were introduced to many cities prior to the first World War to replace cable cars and acted as an alternative to motorised buses during wartime petrol rationing.

In Australia, permanent Trolleybus systems operated in six cities and were characterised by a rubberised wheelbase providing greater manoeuvrability through traffic than fixed guiderail or kerb rail systems, and the use of overhead guidewires for power supply.

Adelaide *(1932 – 1963, five routes),*

Hobart *(1935-1968, six routes on a 22km network),*

Brisbane *(1951-1969, 28km network)*

Launceston *(1951-1968, two routes on a 24km network)*

Perth *(1933 – 1969) and*

Sydney *(1934 – 1959, two unconnected lines).*

They were all removed by the 1970s as the overhead wires were considered unsightly in favour of diesel and petrol buses that didn't require overhead wires, and most systems were removed due to high costs associated with maintenance and extending the network.

Over 500 Trolleybus systems have existed around the world with around 300 current systems using a mix of catenary, magnetic induction, batteries, and combustion engine running technologies.

They are characterised as a hybrid between light rail (with overhead guidewires and near silent operations) and buses (with rubberised wheels suitable for a wider range of terrains and operating environments). They are simultaneously flexible to deploy and maintain due to the absence of in-ground guide rails, large heterogeneous fleet and manufacturers with interoperable technologies, and compatibility with a range of road space allocation environments (including, exclusive corridors separated from general traffic, partially separated or protected corridor and common corridor conditions along the same route).

Trolleybuses are typically viewed as an older solution and, as such, have not been tested recently in Australia. They are well regarded overseas where they form part of the public transport mix for their ability to climb steep grades, achieve low floor accessibility outcomes, e.g. kerb kneeling without the need for additional infrastructure, ability to share electrical infrastructure with trams, and where availability of clean and cheap electricity production is part of existing government policy.

Electric buses and BRTs have evolved from trolleybuses in a range of overseas examples. They are typically powered by an on-board battery that is charged at a depot (this has implications on operating distance, but technology is improving) or have a mix of onboard technologies such as diesel-electric, where a commitment to emissions means that the vehicle travels in electric mode with passengers, and then diesel mode when returning to the depot. Until the technology is sufficiently advanced, operators are finding that to maintain timetabled service delivery, a larger fleet and depot is required, with shorter run times and increased dead running time and cost travelling between service and depot.

2.1.3 Trackless Trams

Trackless trams have been trialled in many locations over a number of years. The most recent approach to trackless trams, also known as Autonomous Rail Transit (ART), caught the attention of the international transport community when it was unveiled by China Railway Rolling Stock Corporation (CRRC) in 2017.

Its optically guided technology draws from high speed rail, and electromagnetic supercapacitor induction umbrellas at stops to recharge batteries instead of traditional lithium-ion batteries seen in electric bus fleets.

Trackless trams started commercial operations in 2019 at the South Chinese cities of Zhuzhou and Yibin (refer to Figure 3). The articulated vehicle is bi-directional (it has a driver cabin at each end) and comprises three sections, each of which has capacity for 100 passengers. With three-carriages, the train is 31.7 metres long, 3.4 metres high and 2.65 metres wide and has a total weight of 48 tonnes. It has a maximum speed of 70 km/h and uses a low-floor layout to facilitate accessibility.

A major advantage of the CRRC system is its multi-axle hydraulic steering technology and bogie-like wheel arrangement, which is designed with less overhang, therefore requiring less clearance in turns. On the Zhuzhou test track, the vehicles require just 3.83 metres of swept path clearance, compared with 5.74 metres for a standard rigid bus.

Partially autonomous, trackless trams make use of a sensor-based assisted driving system, which consists of satellite navigation and several optical and radar sensors along the main body of the vehicle. At the front of the cabin, an optical sensor follows marks printed on the ground (virtual track), "guiding" the trackless tram. Even though the system is called ART, this mostly refers to its capability to ride automated on a track and assisting the driver in manoeuvring (e. g. lane departure warning, collision warning, potential route change authorisation to enable the vehicle to be diverted around blockages, unlike a tram). The driver is still needed to control the vehicle manoeuvres and to evade obstacles[12].

Figure 4: Trackless Tram in the city of Zhuzhou
Source: CRRC Zhuzhou Institute

[12] Sustainable Transport, 2020, Are Chinese trackless trams the best new thing to hit the road in your city?, https://www.sustainabletransport.org/archives/7589, accessed 14/01/21.

2.1.3 Trackless Trams

Overseas experiences

Limitations of trackless trams are documented in a range of overseas examples including:

- *Wright Streetcars were developed specifically to mimic trams with a separated driver compartment, high frequencies, and dedicated stops. They were deployed in York, UK in 2006 and Las Vegas in 2008. The application of the technology into the American context has been challenging due to environmental conditions (desert) which reduces the reliability of the optical sensing technology with flow on impacts to timetabling and maintenance. This technology is being retired early due to reliability issues and availability of parts.*
- *Phileas operates in Eindhoven in the Netherlands. It has an advanced onboard electromagnetic rechargeable battery and drives on a protected bus lane, following a pre-programmed route defined by magnets built into the road at approximately 4metre spacing. There were issues with the navigation system and this ultimately led to the regional authority (SRE) retiring the navigation system from use.*
- *In 2001, about 60% of the Nancy (France) tramway system operated as guided rail, the remaining 40% (11.1km line) an unguided rubber-tyred trolleybus system. The line will be closed and replaced by a conventional low floor tram in early 2023, with conversion work spanning from 2020 to 2022. The system had problems with derailing vehicles, as well as heavy wear and tear of the pavement. Ride quality is also said to be poor and is not much of an improvement over a standard bus due to the four-wheeled design.*
- *Caen (France) installed an electrically powered guided bus (trackless tram) system in 2002 along two routes, on a 15.7km network. The system was plagued with faults, due to design and operation, including a fatality occurring due to the vehicle being restricted to its guiding rail and unable to grip/brake in time.*

The Australian environment

Despite the failings of trackless trams overseas, the core driver causing the trackless tram concept to gain traction in Australia is the comparatively cheaper cost of delivery. The cost of deployment is said to be around 50-65% and 90% cheaper per kilometre than light rail and metro, respectively[13].

Practical Example:
Scarborough Beach to Glendalough Trackless Tram Proposal, Perth

A business case is being completed to determine the merits of establishing Australia's first trackless tram in Perth that would replace existing buses and take passengers a 7km distance from Glendalough to Scarborough Beach. Light rail was not considered along the route as trackless trams are predicted to be able to deliver the service for around a tenth of the price.While the Metro's 25 metre bi-articulated vehicles are a smaller configuration than trackless trams or light rail vehicles (refer Figure 2), as they are a new vehicle technology in Australia, legislative amendments are being required to support their use on our roads.

Source: [14]

Despite the technology's potential cost saving benefit, trackless trams are untested in the Australian context and therefore, the following risks and challenges would need to be considered:

- ***Unproven technology:*** *The technology remains unproven in several environmental conditions, including snow, heavy rain and fog conditions (i.e. environmental constraints may be problematic to operations). Overseas failings (noted previously) have highlighted the need to be cautious with deploying this technology in new environments.*
- ***Regulatory road requirements:*** *Special access to operate on the Australian road network is likely to be required because CRRC's trackless trams are at least 32 metres long. For example, the maximum length of heavy vehicles that can operate on Sydney's roads with "general access" is 19 metres[15 16]. Additionally, road pavements would likely have to be designed specifically for trackless trams. Furthermore, the standard design of roadside barriers may not cater for the dynamic behaviour of trackless trams in an impact situation.*
- ***Monopolised market:*** *Buying trackless trams on a competitive basis may present challenges because of a lack of suppliers , with CRRC currently the only supplier. As the trackless tram is a proprietary technology, there are significant risks associated with being locked into a single supplier. This was seen in almost all instances where onboard cameras and sensors interacted with painted lines or in ground magnets or markers.*

While it is not a viable option currently, due to the considerable risks associated with trackless trams at present, it is considered prudent for governments to undertake a thorough assessment of its potential.

There is a considerable level of latent demand for public transport in the middle and outer suburbs of Australian capitals. This is where the technology may hold its greatest potential as it can be more readily deployed along cross-town and orbital strategic corridors, should governments be able to effectively mitigate the delivery risks.

[13] Yale Wong, University of Sydney, 2019, Debunking the myths around the optically-guided bus (trackless trams), https://www.sydney.edu.au/business/news-and-events/news/2019/01/21/debunking-the-myths-around-optically-guided-bus--trackless-trams.html, accessed 14/01/21.
[14] City of Stirling, 2020, Trackless Tram business case given the green light, https://www.stirling.wa.gov.au/your-city/news/2020/october/trackless-tram-business-case-given-the-green-light, accessed 03/11/20.

[15] The Sydney Morning Herald, 2020, Longer commute, inconvenient, not competitive: Internal report raises trackless tram concerns, https://www.smh.com.au/national/nsw/longer-commute-inconvenient-not-competitive-internal-report-raises-trackless-tram-concerns-20201224-p56pzw.html, accessed 14/01/21.
[16] As trackless trams operate in close proximity to other vehicles and are not on a dedicated track (e.g. light rail), the vehicles need to be regulated.

Australasian Rail Association / Renaissance of Light Rail Report

2.1.4 Light Rail

Light rail or light rail transit (LRT) is a form of urban rail public transportation that, unless in a fully segregated corridor, generally has a lower capacity and lower speed than heavy rail and metro systems, but higher capacity and higher speed than traditional street-running tram systems.

The term is typically used to refer to rail systems with rapid transit-style features that usually use electric rail cars operating mostly in private rights-of-way separated from other traffic but sometimes, if necessary, mixed with other traffic in city streets[17].

Light rail has been utilised to great effect throughout Australian history, particularly in Sydney and Melbourne[18]. With a focus on Sydney, the tramway network served the inner city suburbs from 1879 until 1961 (refer to Figure 4).

At the network's peak in 1945, it was the largest in Australia, the second largest in the Commonwealth of Nations (after London), and one of the largest in the world with track totalling 291km. The network had around 1,600 cars in service at any one time during the 1930s, with patronage peaking at 405 million passenger journeys in 1945[19]. Increased levels of private motor vehicle ownership saw the reallocation of road space from light rail to private vehicles globally. The worsening congestion levels has seen a reversal of this trend in recent years.

The Sydney light rail network has since gone full circle. From the existing tram network being closed in 1961 to accommodate private vehicles and buses, to light rail being reinstated and operational in 2019-20 (refer Figure 5).

Sydney is just one example highlighting the renaissance that light rail has experienced since the new millennium, with no less than 108 cities globally (re)opening their first line. This is supported by the fact that tram and light rail systems are available in around 400 cities across the world[22].

New light rail networks tend to not only enhance the areas they travel through but also deliver significant urban renewal benefits, including increased land values and greater convenience to customers. These characteristics are explored throughout the paper, including the case studies presented in Section A.1.

Figure 5: Trams run along George St outside Townhall in the 1950s [20]

Figure 6: Light rail vehicle moving north along George Street, Sydney [21]

[17] Railsystem, Light Rail Transit, http://www.railsystem.net/light-rail-transit/, accessed 18/01/21.
[18] Refer to Section 3.1 for the case study describing the Melbourne Tram network.
[19] David Goran, The Vintage News, 2016, Trams of Sydney – Sydney once had one of the largest light rail networks in the world, https://www.thevintagenews.com/2016/04/23/trams-sydney-sydney-one-largest-light-rail-networks-world/, accessed 18/01/21.
[20] ABC, 2018, Sydney once had the biggest tram system in the southern hemisphere, https://www.abc.net.au/news/2018-04-12/sydneys-original-tram-network-what-happened-curious-sydney/9610328, accessed 18/01/21.
[21] Railway News, 2019, Sydney L2 CBD and South East Light Rail Opens, https://railway-news.com/sydney-l2-cbd-and-south-east-light-rail-opens/, accessed 18/01/21.
[22] Advancing Public Transport, 2019, The Global Tram and Light Rail Landscape, https://cms.uitp.org/wp/wp-content/uploads/2020/09/Statistics-Brief-World-LRT_web.pdf, accessed 18/01/21.

3. Light Rail Deep Dive

The following sections explore the significant economic, social, and environmental benefits that light rail is proven to provide for the community.

3.1 Benefits

The following sections explore the significant economic, social, and environmental benefits that light rail is proven to provide for the community.

Economic

- ***Catalyst for urban renewal and regeneration:*** *Light rail is proven to help drive considerable land use change, and placemaking and urban renewal outcomes through the catalytic nature of permanent infrastructure, rapidly and safely bringing people to different areas of the city and suburbs.*
    - ***Certainty:*** *Like heavy and metro rail, investment in light rail infrastructure provides certainty of a transport solution that will be provided to the community and local businesses, encouraging property development which drives urban renewal and regeneration leading to increased property values in proximity to stops and fostering wider economic development at a city-wide scale. This is a result of the permanency of tracks that typically have a 100-year design life.*
    - ***Land value uplift and urban renewal:*** *Similarly, light rail in lower density areas, particularly those with limited transport options, can help drive increases in land value and urban renewal and can greatly benefit communities that may have been previously disadvantaged in terms of transport choices.*
    - ***Urban development:*** *Light rail has been associated with increased urban development. The frequency of services and ride quality increases people's willingness to use light rail. This increase in usage can result in an increase in land values due to demand for housing along light rail corridors. This has been demonstrated in Canberra with the revitalisation of Northbourne Avenue and area around Dickson interchange, as well as the revitalisation of London's Docklands precinct in the UK.*

Practical Example: Canberra Light Rail – City to Gungahlin, Canberra

The first stage of the Canberra light rail network, also known as Canberra Metro, is a 12km line that links the northern town centre of Gungahlin to the City centre, known as Civic. It has 13 stops along the corridor, with services commencing operation on 20 April 2019.

The benefits realisation report released by Major Projects Canberra in May 2020, noted an increase in land value and recognised the role of light rail in supporting the ACT Government's broader urban renewal agenda. Specifically it noted "From 2014-2018, average house prices increased by 17% across the whole of the ACT but were higher in the regions incorporating the light rail corridor – 39% in the Inner North and 27% in Gungahlin over the same period."

It goes further to highlight that "The Public Housing Renewal Program has replaced 1288 aged public houses and relocated public housing tenants to newer, higher quality public housing" and that the "Redevelopment of the corridor, particularly Northbourne Avenue is attracting new business and commercial operations, including the new ACT Government office and mixed-use development at the Dickson interchange."

Source: [23]

- ***Cheaper whole of life costs:*** *Light rail might be more expensive to construct than introducing a new bus route, but operationally it is comparatively cheaper to run than other modes resulting in reduced whole of life costs (e.g. lower operating costs per passenger).*
- ***Increased passenger capacity:*** *Light rail can move between 4,000 and 20,000 people per hour in one direction in space equivalent to one lane of road traffic. The same space dedicated to an arterial road lane could move only 800 cars (or less than 1,000 people) per hour, while the same space dedicated to buses would move between 2,000 and 8,000 people per hour[24].*
- ***Networks are scalable:*** *If the appropriate level of planning is undertaken (e.g. potential future connections / alignments are considered), light rail networks (which typically begin with one route) can be expanded over time to align with the changing needs of a city and its broader objectives.*
- ***Adaptable and evolving technology:*** *Light rail is very adaptable, supported by the various technologies (e.g. overhead traction power, ground level power supply and induction systems, traction battery, hybrid battery/supercapacitor, hydrogen fuel cells etc.) that can be tailored to suit the need of the project and context in which the transport system will be operating.*
- ***Ease of use and tourist perception:*** *Good light rail systems have an 'iconic' value that is attractive to tourists, as well as commuters and residents. Where bus routes can be difficult for domestic and international visitors to negotiate, light rail networks are often perceived to be simpler and more reliable, largely owing to the fact that routes are permanent and highly visible, and typically there is no need for timetables. Transport is a key element in the visitor experience and an efficient public transport system can significantly enhance a city's reputation among travellers. In addition, a strong light rail brand can be incorporated into tourism marketing campaigns and information material.*
- ***Integrated networks:*** *While light rail typically serves a more localised demand given comparatively slower operating speeds and short distances between stops compared to heavy rail, it provides access to a larger footprint of employment than is easily reached by the rail network and walking. Furthermore, it often performs an important feeder function to heavy rail which operates at higher speeds with fewer stops, and may also enable rationalisation of an existing bus network.*

Practical Example: Luas Light Rail, Dublin

The fully self-funded Luas tram/light rail system in Dublin now has 67 stops along 42.5km of running track and carries over 48 million passengers annually. There have been four extensions to the existing Green and Red lines since operations began in 2004, and as of 2017, the light rail now successfully intersects and connects within Dublin city centre.

Luas Light Rail highlights that with the right planning, light rail networks can be scaled up over time and operate successfully within increasingly constrained city environments.

Source: [25,26]

[23] https://www.act.gov.au/__data/assets/pdf_file/0007/1544938/City-to-Gungahlin-Light-Rail-Benefits-Realisation-Snapshot-May-2020.pdf
[24] Vuchic, V, 2007, Urban Transit: Systems and Technology, Wiley.
[25] National Transport Authority, 2020, Massive Jump in Passenger Journey Numbers as Commuters Flock to Public Transport, https://www.nationaltransport.ie/massive-jump-in-passenger-journey-number-as-commuters-flock-to-public-transport/, accessed 24/11/20.
[26] Railway Procurement Agency, 2015, Annual Report 2015.

Practical Example: Waterloo Light Rail, Canada

On 21 June 2019, Keolis launched the ION Light Rail Transit (LRT), a rapid transit system in Ontario, Canada. It includes 16km of track and 19 stations to service around 25,000 passengers per day.

There were several incentives for investment into the light rail system, all of which related to providing longer-term environmental and financial sustainability benefits to the community, above which could be provided from a BRT system. A core driver for enabling these benefits is the successful network integration with the region's existing public transport service, the Grand River Transit (GRT). Waterloo Light Rail emphasises the importance of appropriate network integration to realise the maximum benefits for the community.

Source: [27, 28]

Social

- ***Connectivity:*** *Light rail can link education, sports/entertainment, events/conventions, health or mixed employment/residential precincts which require:*
    - ***Turn-up-and-go services:*** *Light rail's operational flexibility allows services to easily meet changing demands when and where required, meaning that users do not need to consult a timetable.*
    - ***High off-peak and weekend frequencies:*** *Lower operating costs with electric vehicles means that light rail is typically operated with high off-peak and weekend frequencies. Non-commuting destinations such as health, education and sports/events precincts tend to have high demand during these periods.*
- ***Improved social cohesion and inclusion:*** *Light rail contributes to community well-being through improving connectivity, accessibility and independence for all commuters.*
- ***Public transport patronage uplift:*** *Light rail can drive an uplift in public transport patronage when it is integrated with other modes. It is often seen as the "spine" of the transport network and given it is highly visible to the public, it raises awareness of public transport and encourages its use. Examples of this include Newcastle Light Rail, Canberra Light Rail and Gold Coast Light Rail (refer to case studies).*
- ***Accessible for all users:*** *Light rail is highly accessible for all levels of mobility (including people with disability and mobility impaired persons, people with prams, tourists with luggage, etc.) as passengers can easily enter the vehicles from raised, level-access platforms.*
- ***Public preference for light rail:*** *Behavioural research continues to find that people prefer to travel by light rail than bus [29]. This is supported by the understanding that passengers globally continually report high satisfaction with the experience, comfort (ride smoothness), reliability, quality, safety and security of light rail. According to a Monash University study [30] that explored the relative merits of both light rail and buses, a number of factors influence a preference for light rail, including:*
    - ***Stations:*** *these are traditionally equipped with better amenities and are easier to locate than bus stops.*
    - ***Network knowledge:*** *due to their direct and fixed nature, rail lines are typically easier to comprehend and navigate than bus routes.*
    - ***Reliability:*** *separation and protection from other forms of traffic improves light rail's reliability whereas road traffic can decrease bus reliability.*
    - ***Priority:*** *separation from traffic provides light rail with priority right-of-way at intersections. Although buses can be provided with priority rights-of-way, its effectiveness can be limited when buses are moving with traffic.*
    - ***Satisfaction:*** *Customers are highly satisfied with light rail services. Transport for NSW data indicates that since 2012, over 90% of customers have been satisfied with light rail services provided in the state [31]. This satisfaction rate is higher than both train and bus services over the same period.*

[27] Grand River Transit, 20202, ION light rail, https://www.grt.ca/en/ion-light-rail.aspx, accessed 25/11/20.
[28] Keolis, 2020, Keolis Canada will operate the project until 2029, https://www.keolis.ca/en/node/234, accessed 25/11/20.
[29] Scherer, Milena. (2010). Is Light Rail More Attractive to Users Than Bus Transit?. Transportation Research Record: Journal of the Transportation Research Board. 2144.
[30] https://www.infrastructureaustralia.gov.au/sites/default/files/2019-06/LightRailVSBus.pdf (accessed 14 May 2021)
[31] Transport for NSW, 2019, Customer Satisfaction Index, November 2019.

Environmental

- ***Reduced environmental impacts:*** *Light rail has a direct, positive impact on greenhouse gas emissions, air pollution, noise, water pollution, urban separation as the vehicles are electrically powered and able to move a comparatively greater number of passengers (e.g. lower costs per km travelled), culminating in reduced traffic congestion, transport-related emissions and a significant number of cars taken off the road. There is also an opportunity for a more sustainable approach to the construction and operation of light rail. This could include 'green track' which involves planting grass or shrubs between and beside light rail tracks [32] or the integration of renewable energy within the network to reduce overall grid dependency.*
- ***Shared pedestrian zones:*** *Light rail is permeable (e.g. easy to cross), comparatively quieter and more sustainable (e.g. reduced localised air quality emissions) with the ability to safely operate alongside pedestrians in shared zones (noting that speeds are typically reduced further in these environments for safety).*
    - *Catenary free tramway systems have been used to open up public places in Bordeaux, Angers, Reims, Orléans, Tours (France), Dubai (UAE), Rio de Janeiro (Brazil), Cuenca (Ecuador), Lusail (Qatar), and Sydney (Australia). The deployment of catenary/pantograph free tramways or ground level power supply (GLPS) has achieved efficient and reliable performance since around the early 2000.*
    - *Technology to support on board energy storage systems (OESS) have become more prevalent in the last decade. The improvements to these technologies will gradually reduce the mass of vehicles (size of batteries, weight of vehicles) and produce less strain on the underlying pavement conditions. Improvements in battery technology will extend running times, and increase the distances that can be travelled between stops/charging stations.*

[32] NSW Government, 2019, Green track for Parramatta Light Rail, http://www.parramattalightrail.nsw.gov.au/news/green-track-parramatta-light-rail#:~:text=Parramatta%20Light%20Rail%20will%20feature,Thomas%20Reserve%20and%20Tramway%20Avenue., accessed 28/10/20.

Practical Example: Newcastle Light Rail, Newcastle

Newcastle light rail, which opened in 2019, runs from the major transport interchange through the CBD area. The project has been key to activating the precinct by setting in motion the removal of the heavy rail line into Newcastle which caused a physical divide through the city for several decades.

Newcastle Light Rail has resulted in a more activated precinct that better connects the previously divided sides of the city whilst encouraging healthier lifestyles within the community through more active transport activities such as walking and cycling.

Source: [33]

Practical Example: Yarra Trams, Melbourne

Melbourne has expanded over time to become the world's largest operational tram network with 250km of double track (75% of which is shared with other vehicles) supporting over 200 million trips annually across the city, resulting in it being one of the busiest light rail networks in the world.

The scale and use of the network have resulted in material, social, and environmental benefits for the local community. A report by Keolis Downer (2016) indicates that the tram network:

• Contributes between $730 and $870 million to Melbourne's social fabric every year.
• Saves $75 – $97 million in environmental damage and is 82% less greenhouse gas emissions intensive than driving.
• Increases connectivity, accessibility, independence, and improved well-being for Melbournians who utilise the network.

The Yarra Trams network in Melbourne highlights the considerable social and environmental benefits that can be realised from a light rail network, particularly when it operates at a city-wide scale.

Source: [34,35,36]

[33] Newcastle Herald, 2016, Newcastle heavy rail corridor removal complete by Baird government, https://www.newcastleherald.com.au/story/4363931/heavy-rail-corridor-gone-as-removal-complete/, accessed 12/01/20.
[34] Yarra Trams, 2020, Facts and figures, https://yarratrams.com.au/facts-figures, accessed 19/11/20.
[35] Keolis Downer, 2016, An Economic, Environmental and Social Analysis of Melbourne's Tram Network.
[36] Advancing Public Transport, 2019, The Global Tram and Light Rail Landscape, https://cms.uitp.org/wp/wp-content/uploads/2020/09/Statistics-Brief-World-LRT_web.pdf, accessed 13/01/21.t

Practical Example: Canberra Light Rail Stage 1, Canberra

Canberra Light Rail Stage 1 has successfully achieved zero net emissions through various initiatives including the purchase of carbon offsets to offset construction emissions, the installation of solar panels on the roof of the vehicle depot and solar powered lights. A study released by the Canberra Urban Regional Futures established that the light rail would result in about 2,900 to 4,700 tonnes of greenhouse gas emissions per year being eliminated from the transport sector, translating to a 18 to 30 percent emission reduction on the City to Gungahlin corridor in 2020 compared to business-as-usual.

In addition to the environmental benefits, survey data collected in 2021 indicates that the light rail operation has enticed many Canberrans to try out public transport for the first time, with more than two-thirds saying they were more likely to use public transport now than previously.

Canberra Light Rail emphasises the significant renewable energy opportunities that exist for light rail projects which should be explored during the planning and design development phases.

Source: [37,38]

[37] ACT Canberra, 2015, Study confirms environmental benefits of light rail for Canberra, https://www.cmtedd.act.gov.au/open_government/inform/act_government_media_releases/corbell/2015/study-confirms-environmental-benefits-of-light-rail-for-canberra#:~:text=%E2%80%9CAccording%20to%20the%20study%2C%20light,buses%2C%E2%80%9D%20Mr%20Corbell%20said.&text=This%20elimination%20of%20emissions%20is,free%20of%20greenhouse%20gas%20emissions.%E2%80%9D, accessed 14/01/21.
[38] ACT Government, 2021, Light rail continues to drive increased public transport uptake, Media release, 8 April 2021.

3.2 Challenges

Detailed below are the key challenges, risks and impacts associated with light rail infrastructure:

- ***Higher construction costs driving increased modal competition:*** *There is a risk that light rail may be considered less desirable than other alternative transport modes (e.g. trackless trams, BRT) as it may be comparatively more expensive to construct. However, depending on the transport scenario, BRT systems can also be costly if high capacity movements are required to service the need (e.g. the provision of appropriate space for buses to turn around at the end of the route, which may require multi-level bus interchanges, passing lanes around stops and tunnels (wider/passing lanes)). As noted above, it is critical to consider the broader opportunities and objectives of the project, when considering light rail options.*

- ***Visual amenity impacts:*** *Visually intrusive overhead line equipment (OHLE) and the difficulties of implementing the infrastructure in a heavily constrained brownfield environment. OHLE may also cause consequential impacts to the natural and built environment. In some cases, this can be overcome by in ground power supply or other power solutions.*

- ***Stakeholder support:*** *The general perception of light rail infrastructure and the land use benefits it can bring to a city are not widely understood. Furthermore, land use changes from light rail resulting in rezoning, high-rise developments or increased population density may not be outcomes that are wanted by the local community. Although there are challenges in achieving stakeholder support and buy-in, involving government and other key stakeholders throughout the development process will support complementary investment in place-making to support development of high-amenity precincts.*

- ***Transport mode prioritisation:*** *Light rail is far more successful when it is given modal prioritisation. This allows the system to work effectively while also supporting greater pedestrianisation and active transport use along the alignment. If this does not occur, there is a risk that travel times may not be competitive when compared to other modes, particularly if priority is given to cars and buses over light rail vehicles.*

- ***Long planning and project development lead times:*** *Over long periods, there is a risk that government policy can change, or more generally, community and political support for the project diminishes. This emphasises the importance of maintaining project and network development momentum.*

- ***Value capture:*** *Land value uplift generally occurs when there is government commitment (before construction is complete), which can create challenges for achieving successful value capture (or sharing) mechanisms. However, there are mechanisms that government can leverage to ensure they capitalise on the opportunity. For one light rail project in Dublin, the government required a project-specific contribution of €55,000 for each new residential unit built within 1.5km of the rail line. It was found that proximity to the rail line added, on average, €155,000 to the value of each property in that area, clearly demonstrating that the public sector and local homeowners were sharing the value produced by the rail line [39].*

- ***Inducing development demand:*** *Opponents of light rail believe that support for other modes (e.g. electric buses and trackless trams) will protect them from overdevelopment. Because light rail has a design life of up to 100 years, it allows growth to be coordinated in a systemic deliberate fashion. Other modes have the benefit of flexibility and are well suited to areas experiencing significant growth/decline in population and can be rapidly deployed to address these needs in a short period of time. They risk ad hoc growth around alternate centres resultant in congestion and poor transport outcomes that are distributed throughout the network.*

- ***Limited opportunities to reduce operational costs and network efficiency:*** *Some of the benefits of driverless vehicles (or self-propelled autonomous transport systems) include reduced operational costs, increased network efficiency and improved safety from the avoidance of human error. However, light rail, like trackless trams and buses, typically operate in transient environments where driverless technology is not nearly as effective. For this reason, unless a light rail system is fully segregated, the use of driverless vehicles is unlikely to occur until the technology improves.*

- ***Construction risks:*** *Light rail infrastructure is typically developed in-situ within constrained 'brownfield' areas (e.g. existing road alignments) in close proximity to established urban environments. There are inherent construction risks during excavation works (e.g. varying levels of underground services and quality of service location data) and other activities that can result in long-term financial and amenity impacts for local businesses and the community.*

[39] Deloitte, 2019, The virtues of value capture, https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Public-Sector/smart-cities-virtues-of-value-capture-19nov.pdf.

Practical Example: CBD and South East Light Rail, Sydney

The presence of unknown utilities along the CBD and South East Light Rail alignment resulted in extensive delays and additional costs during the construction phase. These delays were compounded by the dispute resolution that occurred between the NSW Government and contractor delivering the project.

To support impacted businesses during the construction period, the NSW Government provided rental assistance (along with other programs). The delayed program and small business assistance packages added around $118 million in additional costs to the project.

CBD and South East Light Rail highlights that there is inherent construction related risks associated with delivering light rail within brownfield development areas (which is typically the case) that in future, should be mitigated prior to the commencement of construction activities.

Source: [40, 41]

[40] NSW Parliament – Public Accountability Committee, 2019, Impact of the CBD and South East Light Rail Project.
[41] Government News, 2020, Cost of Sydney light rail blows out, reporting questioned, https://www.governmentnews.com.au/cost-of-sydney-light-rail-blows-out-reporting-questioned/#:~:text=The%20cost%20of%20Sydney's%20troubled,when%20the%20contract%20was%20signed.&text=Transport%20for%20NSW%20has%20failed,cost%20of%20the%20troubled%20project., accessed 02/11/20.

4.
Decision Making Framework

4.1 Modal Comparison

Table 1 provides a summary of the transport options to differentiate their respective roles in an integrated transport network highlighting that the suitability of the mode should be driven by the transport or land use outcome desired.

This table is not designed to be a definitive evaluation of different modes and technologies, and should be read in context of the decision making framework outlined in Figure 6.

Theme	Bus	BRT (on road)	Trackless Tram	Light Rail [47]	Heavy Rail
Description	• On-street buses (potential for painted bus lanes) with frequent stops	• Segregated bus route (can be open or closed systems) with larger vehicles and less frequent stops	• Vehicle with rubber wheels (can be on-road or segregated and potential for autonomous guidance)	• Vehicle with tracks and overhead wiring or wireless operation (can be on-road or segregated)	• Connected vehicles with tracks and overhead wiring
Tracks	✗	✗	✗	✓	✓
Fuel/Energy	• Diesel / gas / electric	• Diesel / gas / electric	• Diesel / gas / electric	• Electric	• Electric [48]
Stop Type	• Shelters only	• Raised platforms and shelter	• Raised platforms and shelter	• Raised platforms and shelter	• Raised platforms and shelter
Distance between sopts	• Range of approx.. 200-400 m	• Range of approx.. 800-1,000 m	• Range of approx.. 600-1,200 m	• Range of approx.. 500-1,200 m	• Wide range. Average of approx.. 1,000-2,000 m
Service frequency	• 5-10 mins (busy route) • 15-30 mins (other)	• < 10 mins	• 2 to 3 mins	• 2 to 3 mins	• 5-10 mins (busy route) • < 30 mins (other)
Capacity per vehicle	• 80 persons	• 110-180 persons	• 300 persons (100 sitting, 200 standing)	• 300 persons (100 sitting, 200 standing)	• 900 persons (on 8 car Sydney

Table 1: A Comparison of the Typical Transport Modes [42,43,44,45,46]

[42] NSW Government, 2012, Sydney's Light Rail Future, https://www.transport.nsw.gov.au/sites/default/files/media/documents/2017/sydneys-light-rail-future.pdf, accessed 12/10/20.
[43] Transport for NSW, 2016, Principles and Guidelines for Economic Appraisal of Transport Investment and Initiatives, https://www.transport.nsw.gov.au/sites/default/files/media/documents/2017/principles-and-guidelines-for-economic-appraisal-of-transport-investment.pdf, accessed 12/10/20.
[44] Alternative and deferral options assessments for Sydney Metro West and Western Sydney Airport (formerly Greater West)
[45] United States Department of Transportation, 2004, Characteristics of Characteristics of Bus Rapid Transit Bus Rapid Transit, https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/CBRT.pdf, accessed 29/10/20.
[46] Sydney Trains, 2019, Annual Report, file:///C:/Users/angelo.rouggos/Downloads/Sydney-Trains-Annual-Report-V1-2018-19.pdf, accessed 13/01/20.
[47] While there is work being undertaken on autonomous light rail technology that will present future opportunities for the transport mode, these have not been explored in this paper.
[48] France is going to integrate hydrogen powered trains into their fleet.
Railexpress, 2021, First order of hydrogen trains in France hailed as "historic step" towards sustainable mobility, https://www.railexpress.com.au/first-order-of-hydrogen-trains-in-france-hailed-as-historic-step-towards-sustainable-mobility/, visited 12/04/21.

Theme	Bus	BRT (on road)	Trackless Tram	Light Rail	Heavy Rail
Speed	• 60 km/hr	•90 km/hr	• 60 km/hr (open) to 70 km/hr (segregated)	• 60 km/hr (open) to 80 km/hr (segregated)	• 130 km/hr
Operating Gradient	• Typical bus with motorised rubber tyres can manage up to 9% gradients • Trolley bus capable of gradients up to 22% with increased power supply and 13% with typical use.	• High quality bus corridors with smoother gradients and curvature will offer better ride quality.	• This technology is not yet proven in mixed road conditions.	• Typical use limited to 6%	• Typical use is restricted to 4%, ideally any track shared with freight would be less than 1.5%
Safety	• Low – shared space with other vehicles	• Low – if shared with other vehicles • High – when segregated	• High – when segregated	• High – when segregated. Speeds are reduced in pedestrian areas to maintain safety	• High
Amenity	• Higher noise and emissions (potential to reduce with gas and electric vehicles)	• Higher noise and emissions (potential to reduce with gas and electric vehicles)	• Visual amenity from vehicles • Emissions depend on energy source used	• Quiet (bells required in pedestrian areas) and low emissions from electric vehicles • Opportunities for pedestrianisation of streets	• Visual amenity from vehicles • Comparatively lowest emissions per passenger km
Reliability	• Highly variable depending on route and time of day [49]	• Medium to High	• Medium to High	• High (97% on-time running)	• Medium to High (91% on time running)

With the exception of heavy rail, each mode offers significant flexibility in terms of service frequency. The minimum headway between services and vehicle dwell times, is a function of demand, priority and degree of separation, protection, of integration with general traffic along the corridor.

The ability for a mode to achieve the target frequencies is typically a strategic network decision. Travel speeds and headways can be limited by the level of priority afforded at signals for different movements throughout the day.

[49] While buses can be heavily reliant on other road traffic, where necessary they have the added ability to alter their route to avoid unforeseen traffic conditions (e.g. breakdowns).

4.2 Framework

A key outcome of this paper is the development of a robust framework that can be used to determine which transport mode in what context is most suitable. As detailed previously in Section 2.1.2, while the integration of trackless trams within the wider transport network may have merit in the future, the technology is untested in the Australian market and has therefore not been considered in the framework.

Through consolidating the insights gained from the modal comparison, along with a review of several local and international case studies, RPS developed a transport planning decision-making framework that uses a Red-Amber-Green (RAG) ranking against key decision making criteria (refer Figure 6) to help determine the most appropriate modal choice through consideration of a project's context and the outcomes it is attempting to achieve.

The framework is made up of a set of considerations essential to choosing the right public transport mode to deliver on the project objectives. The conditions assess each mode choice against the following considerations:

Urban renewal/land value uplift - ability to generate some form of land value and density uplift along the corridor it is servicing

Amenity - ability to provide amenity, both at the stop and during the journey (included ride smoothness, accessibility, legibility, real time information, announcements, seating)

Stop frequency - total catchment served, with a higher number of stops per kilometre resulting in more of the population being within walking distance of public transport

Reliability/proven technology - ability to provide on time services via a proven mode of transport

Patronage - ability to move a large number of people easily and efficiently through frequency of services or length/size of vehicle

Service frequency - ability to increase or decrease service frequency easily

Travel time saving - ability to improve travel times across multiple different types of trips

Delivery constraints - the complexity of delivery and affordability of both fixed infrastructure and fleet

Flexibility in routes - ability to move or change routes easily

Budget considerations have not been accounted for in the framework as they are unique to each project and should be weighed against the relative benefits and objectives of each project.

	Patronage	Delivery constraints	Reliability	Flexibility in routes	Urban renewal and value uplift	Travel time savings	Stop frequency	Service frequency	Amenity
Bus	⚫	🟢	⚫	🟢	⚫	⚫	🟢	⚪	⚪
BRT (on road)	⚪	⚪	⚪	⚪	⚪	⚪	🟢	🟢	⚪
Light Rail	🟢	⚫	🟢	⚫	🟢	🟢	⚪	🟢	🟢
Heavy Rail	🟢	⚫	🟢	⚫	🟢	🟢	⚫	🟢	🟢

Key

⚫ Is not well placed to meet this criterion ⚪ Partially meets this criterion 🟢 Delivers well against this criterion

Figure 6: Decision Making Framework

Extending on the framework presented in Figure 6 this paper has assessed a range of projects against the criteria in section 4.4 below.

4.3 Findings

The research team has found that:

1. Buses and advancing bus technologies (such as electric BRTs, trolleybuses and electrically/optically guided bus systems) are well suited to corridors that are experiencing changing travel patterns, require stop relocation and route flexibility.
2. BRT and other protected vehicles are well suited to corridors with high patronage demand throughout a movement corridor.
3. Light Rail is well suited to transport projects that seek to help catalyse a land use change whilst being capable to meet high patronage demand throughout a movement corridor.
4. Heavy Rail is well suited when you need to move high numbers of passengers across larger distances and catalyse key employment and residential centres.

4.4 Applying the framework to recent project proposals

While an integrated multi-modal approach is the most effective mechanism to achieve optimal transport outcomes, government has an obligation to taxpayers (who ultimately fund transport projects) to invest in the most economically viable transport mode that achieves the project objectives. The framework identifies that light rail is well placed to deliver on project objectives that include:

- Patronage
- Reliability
- Urban renewal/land value uplift
- Stop frequency
- Service frequency
- Travel time savings
- Amenity

A number of light rail projects and their respective objectives have been used to test the criteria in the assessment framework. This is shown below.

Auckland Light Rail

Seeks to expand the public transport network and unlock Auckland's urban development opportunities and make it easier to move around the city to work, study and socialise by creating a new rapid transit corridor. The Auckland project aims to expand the public transport network by connecting the light rail network to established transport hubs (e.g. heavy rail or major bus interchange).

It forms part of a multi-modal transport network and includes a suitable level of network integration (e.g. minimal transfer distances for passengers at bus or rail interchanges, efficient timetabling). A seamless interchange between transport modes is important to the overall customer experience and public transport patronage levels.

An assessment of the key project objectives is shown below.

Theme	Objectives	Bus	BRT (on road)	Light Rail (prioritised)	Heavy Rail
Urban renewal/ land value uplift	• Enabling of quality integrated urban communities, especially around Māngere, Onehunga and Mt Roskill	✗	○	✓	✓
Amenity	• Optimised environmental quality and embedded sustainable practices	○	○	✓	✓
Stop frequency		✓	✓	○	●
Reliability	• A high quality service that is attractive to users, with high levels of patronage.	✗	○	✓	✓
Patronage	• A high quality service that is attractive to users, with high levels of patronage.	✗	○	✓	✓
Service frequency	• Improved access to opportunities through enhancing Auckland's Rapid Transit Network and integration with Auckland's current and future transport network	○	✓	✓	✓
Travel time savings		✗	○	✓	✓
Delivery constraints	• Improved access to opportunities through enhancing Auckland's Rapid Transit Network and integration with Auckland's current and future transport network	✓	○	○	●
Flexibility in routes		✓	○	○	●

Sunshine Coast Mass Transit Project

seeks to develop an integrated transport solution that will accommodate the 200,000 people who are expected to move to the Sunshine Coast in the next 20 years. It is expected that most growth will occur in the Maroochydore and Caloundra corridor and most trips (74%) will be less than 10kms.

The Sunshine Coast tourism sector is valued at over $2.7 billion and derives significant revenue from the visitor economy. The proposed project connects off-peak destinations to provide operational flexibility and allows services to easily meet changing demands which is important for off-peak destinations.

An assessment of the key project objectives is shown below.

Theme	Objectives	Bus	BRT (on road)	Light Rail (prioritised)	Heavy Rail
Urban renewal/ land value uplift	• Support jobs, tourism and a stronger economy • Support greater housing choice	✗	○	✓	✓
Amenity	• Create better connections between key destinations • Promote more vibrant neighbourhoods	○	○	✓	✓
Stop frequency		✓	✓	○	●
Reliability	• Support jobs, tourism and a stronger economy • Help reduce growth in traffic congestion	✗	○	✓	✓
Patronage	• Create better connections between key destinations • Help reduce growth in traffic congestion	✗	○	✓	✓
Service frequency		○	✓	✓	✓
Travel time savings		✗	○	✓	✓
Delivery constraints		✓	○	○	●
Flexibility in routes		✓	○	●	●

This suggests that a light rail solution is viable to meet the project's objectives and should be explored further.

4.4 Applying the framework to recent project proposals

Newcastle Light Rail

Seeks to support Greater Newcastle as a dynamic and entrepreneurial economy and lifestyle city, with a customer centric, multi-modal network that further enables and activates Greater Newcastle.

A core driver for light rail consideration is its ability to enable placemaking and urban renewal outcomes proximate to station locations. Land value uplift is a key outcome of light rail infrastructure.

Light rail provides wider land value uplift opportunities along the alignment that are over and above what would occur without light rail and includes significant placemaking and urban renewal opportunities. The inclusion of the Broadmeadow Urban Renewal and Entertainment Precinct, as well as the John Hunter Hospital redevelopment; is expected to produce the highest employment growth rate of any of the route options that were considered.

An assessment of the key project objectives is shown below.

Theme	Objectives	Bus	BRT (on road)	Light Rail (prioritised)	Heavy Rail
Urban renewal/ land value uplift	• Support a new economy • support workforce and education opportunities for the new economy • Open opportunity - support housing close to jobs and services	✗	○	✓	✓
Amenity	• Enhance the environment - enhance environment, amenity and resilience for quality of life	○	○	✓	✓
Stop frequency	• Improve access - provide multi-modal connectivity to jobs, services and recreation	✓	✓	○	●
Reliability	• Support a new economy - support workforce and education opportunities for the new economy • Improve access - provide multi-modal connectivity to jobs, services and recreation	✗	○	✓	✓
Patronage	• Enhance the environment - enhance environment, amenity and resilience for quality of life • Improve access - provide multi-modal connectivity to jobs, services and recreation	✗	○	✓	✓
Service frequency		○	✓	✓	✓
Travel time savings		✗	○	✓	✓
Delivery constraints		✓	○	○	●
Flexibility in routes		✓	○	●	●

The framework considers that Newcastle Light Rail Stage 2 is well aligned to the objectives that can be delivered by light rail.

Gold Coast (Stage 4)

seeks to create a high quality, world class transport service which will improve the connectivity of the Gold Coast's current public transport system with more efficient transportation options.

An assessment of the key project objectives is shown below.

Theme	Objectives	Bus	BRT (on road)	Light Rail (prioritised)	Heavy Rail
Urban renewal/ land value uplift	• Contributes to the local economy • Contributes to regional growth	✗	○	✓	✓
Amenity	• Better active transport	○	○	✓	✓
Stop frequency	• Accessibility	✓	✓	○	●
Reliability	• Improve Safety • Improves Network efficiency • Reduces peak hour congestion • Reduces Maintenance	✗	○	✓	✓
Patronage	• Accessibility	✗	○	✓	✓
Service frequency	• Improves Network efficiency • Reduces peak hour congestion	○	✓	✓	✓
Travel time savings	• Reduces travel time	✗	○	✓	✓
Delivery constraints		✓	○	○	●
Flexibility in routes		✓	○	●	●

Confirming that further investment in light rail on the Gold Coast will continue deliver project objectives.

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4.4 Applying the framework to recent project proposals

Canberra Metro (Stage 2B)

Seeks to create a high quality, world class transport service which will improve the connectivity of the Canberra's current public transport system with more efficient transportation options.

Theme	Objectives	Bus	BRT (on road)	Light Rail (prioritised)	Heavy Rail
Urban renewal/ land value uplift	• Shape and Place – Frame the future shape of development along the corridor while reinforcing the identity of existing communities and provide early delivery of city-wide initiatives for urban renewal and diversity of place • Liveable and productive – Build a productive, diversified and smart economy by making Canberra a more attractive place to live work and invest	✗	○	✓	✓
Amenity	• Shape and Place – Frame the future shape of development along the corridor while reinforcing the identity of existing communities and provide early delivery of city-wide initiatives for urban renewal and diversity of place • Environment – Reduce emissions and promote sustainable urban form for the benefit of current and future generations • Community – Provide a connected, accessible public transport network that strengthens opportunities for social and economic participation • Liveable and productive – Build a productive, diversified and smart economy by making Canberra a more attractive place to live work and invest	○	○	✓	✓
Stop frequency	• Accessibility	✓	✓	○	●
Reliability	• Connectivity – provide a north-south public transport spine that represents the next stage of a future city-wide light rail network that connects communities across Canberra • Transport choice – Provide Canberrans with an attractive, convenient, efficient and reliable integrated public transport system that facilitates choice, increases public transport patronage and reduces car dependency • Community – Provide a connected, accessible public transport network that strengthens opportunities for social and economic participation	✗	○	✓	✓
Patronage	• Transport choice – Provide Canberrans with an attractive, convenient, efficient and reliable integrated public transport system that facilitates choice, increases public transport patronage and reduces car dependency	✗	○	✓	✓

Theme	Objectives	Bus	BRT (on road)	Light Rail (prioritised)	Heavy Rail
Patronage	• Transport choice – Provide Canberrans with an attractive, convenient, efficient and reliable integrated public transport system that facilitates choice, increases public transport patronage and reduces car dependency	✗	○	✓	✓
Service frequency	• Connectivity – provide a north-south public transport spine that represents the next stage of a future city-wide light rail network that connects communities across Canberra • Transport choice – Provide Canberrans with an attractive, convenient, efficient and reliable integrated public transport system that facilitates choice, increases public transport patronage and reduces car dependency • Community – Provide a connected, accessible public transport network that strengthens opportunities for social and economic participation	○	✓	✓	✓
Travel time savings		✗	○	✓	✓
Delivery constraints	• Value and innovation – Deliver the Territory an affordable Project solution that drives innovation and provides a value for money outcome.	✓	○	○	●
Flexibility in routes		✓	○	●	●

The objectives of the Canberra Metro Stage 2B align well with the proposed framework and indicate that the light rail extension would continue to deliver on the key project objectives for the ACT Government and Canberrans.

Australasian Rail Association / Renaissance of Light Rail Report

Non Light Rail Assessment

To contrast the light rail project examples, it was considered prudent to assess a project that would not align with a light rail solution. Brisbane Metro was considered a good project to demonstrate this differentiation.

Brisbane Metro (Stage 1)

The first stage of Brisbane Metro will provide a 21km service connecting 18 stations along dedicated busways between Eight Mile Plains and Roma Street, and Royal Brisbane and Women's Hospital and University of Queensland. It is to enhance and augment an existing bus network.

Its objectives are outlined below:

Theme	Objectives	Bus	BRT (on road)	Light Rail (prioritised)	Heavy Rail
Urban renewal/ land value uplift		✗	○	✓	✓
Amenity	• Improve legibility and connectivity issues in an efficient manner • Address worsening inner city amenity	○	○	✓	✓
Stop frequency	• Improve accessibility and connectivity • Provide sufficient effective capacity	✓	✓	○	●
Reliability	• Improve journey times and reliability • Address operational inefficiencies	✗	○	✓	✓
Patronage		✗	○	✓	✓
Service frequency	• Improve accessibility and connectivity • Provide sufficient effective capacity	○	✓	✓	✓
Travel time savings	• Improve journey times and reliability	✗	○	✓	✓
Delivery constraints	• Improve legibility and connectivity issues in an efficient manner	✓	○	○	●
Flexibility in routes	• Address operational inefficiencies	✓	○	●	●

The objectives of the Brisbane Metro (Stage 1) align well with the proposed framework and indicate that, while there is some alignment to light rail capabilities, a BRT would align much better in delivering the objectives of the project. The difference is principally driven by the focus on operational efficiencies, some flexibility in route design, improved corridor operations and not seeking to drive any specific urban renewal outcomes.

Australasian Rail Association / **Renaissance of Light Rail Report**

4.5 Policy Recommendations

Based on the findings from this research paper and lessons learned from the various local and international case studies, RPS has developed the following policy recommendations for government consideration to further support the integration of light rail infrastructure within our cities' transport networks and optimise the delivery of the next wave of light rail investment.

Recommendation 1: Refine the policy framework to assess light rail projects more appropriately

It is important that in assessing the impact of light rail an appropriate business case and appraisal framework is used. One that values the impact on 'place' rather than just 'movement' and the transformational impact that light rail projects can have on centres and communities.

- Recommendation 1.1: Government(s) reform the business case and appraisal approach to better consider land use, urban renewal and 'place' outcomes alongside conventional transport benefits.

  This includes not only developing consistent approaches to measuring these benefits but also recognising the contribution that transport projects have to the urban realm and creation of new public places. It is noted that Infrastructure Australia is currently reviewing its framework to support a more holistic approach to project assessment.

  In order to achieve the travel times and service frequencies in shared and dedicated corridors, light rail requires signal and kerb priority. Not only is it critical that the impact of this prioritisation on other modes within the project study area but also the broader network effect of these trade-offs against operational performance of other modes in the network in order to realise the place and environment benefits from light rail. E.g. if light rail receives kerb priority but not signal priority, green time for the alternative movement is underutilised and may create additional congestion in other parts of the network.

- Recommendation 1.2: Optimisation of the light rail network (through signal priority) is considered during the business case concept design development phase to establish a more accurate portrayal of timetable performance throughout the day and optimise service delivery.
  It is difficult for transport agencies to deliver all the projects benefits alone. Therefore, early and ongoing engagement with all levels of government and key stakeholders throughout the process will enable the development of a light rail system that meets the needs of all relevant parties, while achieving the greatest benefits realisation. Stakeholder engagement can also be supported by other mechanisms (e.g. co-sponsored business cases, memorandums of understanding, inclusion of governance for benefits realisation).

- Recommendation 1.3: Stakeholder engagement during the planning and development phases of a light rail project transition from a preferred approach to a government assurance requirement (e.g. as co-sponsors of a business case). This may be a continuation of engagement undertaken as part of the corridor and/or land use planning.

4.5 Policy Recommendations

Recommendation 2: Develop a co-ordinated funding approach

Successful light rail projects require a co-ordinated approach to investment and funding, involving both the public and private sectors.

Current funding models do not allow Australia to derive full value from land price uplift generated by its transport infrastructure investments. Recent examples of light rail development have seen state and municipal transport authorities identify needs and justify feasibility independently of local councils and authorities.

This has resulted in delays due to location of utilities, interfacing and operational asset risks, poor trader and resident outcomes, vague, ambitious and optimistic expectations for mode shift and separation outcomes.

- Recommendation 2.1: Where possible, governments seek council stakeholders as sponsors/owners of light rail business cases.
- Recommendation 2.2: To minimise funding delays, Federal Government to identify what it requires to support investment in light rail projects.
- Recommendation 2.3: To reduce a project's overall cost to government(s), earlier action should be taken to capitalise on value-capture opportunities that exist well before construction commences (e.g. during the planning and development phase). An example of this could include coordinated corridor protection activities [50].
- Recommendation 2.4: Government(s) assess the benefits of introducing a direct land contribution obligation for landowners following rezoning to provide early and adequate funding for land [51]. Equally government(s) should also consider the introduction of a transport levy that provides a balanced approach to fund local projects using ratepayer contributions [52].

Recommendation 3: Reduce delivery phase risks through an improved risk sharing approach

The current approach taken by government to delivering large scale transport infrastructure projects (>AU$500 million) puts high levels of risk onto contractors.

This is compounded by the fact that they typically operate under fixed price contracts with low margins. Consequently, an increasing number of projects have experienced significant cost blowouts, with adverse impacts on both the public and private sectors.

- Recommendation 3.1: Where there are potential significant construction related risks, a greater level of investigation should be undertaken as part of the project development phase to provide a more accurate representation of predicted project costs. Furthermore, in cases where this is not possible, a collaborative procurement approach where risks are appropriately shared between the contractor and government should be established (e.g. Alliance model).
- Recommendation 3.2: Utilities have posed a large risk across multiple light rail projects. It is recommended that this risk is specifically targeted in early development phases of the project, with greater knowledge sharing and transparency between utility providers and light rail proponents (including sharing of utility locations and ensuring new utilities are appropriately mapped), so that this risk is proactively mitigated.

[50] The Parliament of the Commonwealth of Australia, 2020, Fairer funding and financing of faster rail Inquiry into options for financing faster rail.
[51] This mechanism, which has been outlined in detail in the NSW Productivity Commission, will improve both efficiency and certainty for funding and land acquisi tion. NSW Government, 2020, Review of Infrastructure Contributions in New South Wales – NSW Productivity Commission – Final Report.
[52] This has been successfully adopted by the City of Gold Coast and Sunshine Coast Council in Queensland.

A.1 Detailed Case Studies

There are several light rail systems operating in Australia, with several more in either the planning, design or construction phases. A review of two light rail systems has been undertaken to establish the network's general characteristics, original drivers, integration with the existing transport network, success factors and ongoing legacy they will leave their respective cities.

A 1.1 Gold Coast Light Rail

Gold Coast Light Rail (GCLR) is the biggest transport infrastructure project ever undertaken on the Gold Coast. The planning of Stage 1 began in 2009 with funding provided by the Federal and Queensland governments, as well as Gold Coast Council.

Within three years of the successful opening and operations of Stage 1, the Queensland Government announced plans to extend the light rail line. This success has continued resulting in the imminent Stage 3 and Stage 4 extensions being developed to respond to the city's predicted growth.

- ***Stage 1:*** *13km light rail from Parklands to Broadbeach. Completed in 2014.*
- ***Stage 2:*** *7.2km northern extension from Parklands to Helensvale. Completed in 2017*
- ***Stage 3:*** *6.7km southern extension from Broadbeach South to Burleigh Heads. This stage is funded, with construction expected to commence in 2021* [53]*.*
- ***Stage 4:*** *13km light rail from Parklands to Broadbeach. Completed in 2014.*

Figure 7: Gold Coast Light Rail Route Alignment Map [54]

A summary of the GCLR project is provided in Table 2.

General Characteristics		
Operation 20 July 2014	**Total Distance** 20 km	**Average Speed** 27 km/hr
Operator Keolis Downer	**No. Stations** 19	**Top Speed** 70 km/hr
Construction Cost Stage 1: $1.5 billion Stage 2: $420 million Stage 3: $709 million (construction commencing in 2021)	**Patronage** Annual patronage Year 1 (2014/15): 6.3 million Year 2 (2015/16): 7.7 million (+22.3% growth) Year 3 (2016/17): 8.0 million (+3.9% growth) Year 4 (2017/18): 9.5 million (+18.9% growth) Year 5 (2018/19): 10.7 million (+13.2% growth)	
Original Drivers		
Future proofing the transport network Projections for population growth in the mid 1990s identified more accessible public transport and efficient use of roads would be required to address future traffic congestion.	**Strategic drivers** Light rail has been identified in various South East Queensland strategic planning documents and studies since the 1990s.	
Original Drivers		
Stage 1 – Corridor establishment Focus on establishing the 'spine' in the core section of the network, from Gold Coast University Hospital to Broadbeach, connecting major destinations including Griffith University, Southport CBD, Broadwater Parklands, Surfers Paradise, Gold Coast Convention and Exhibition Centre, and Pacific Fair shopping centre.	**Stage 2 – Heavy rail link** Provision of a vital integration with the Gold Coast to Brisbane CityTrain (heavy rail) line at Helensvale, providing inter-regional connectivity and boosting patronage for the heavy and light rail networks. The system also supported the 2018 Commonwealth Games through connecting a number of games venues with accommodation centres and the athletes village.	

Table 2: Case Study – Gold Coast Light Rail [55,56,57,58,59]

The GCLR exceeded all expectations with regards to patronage, reaching Year 2 patronage figures within its first nine months of operations [60]. The factors that influenced this success include:

- ***Strategic alignment:*** *Measures align with three key themes (Place, Prosperity, People) in the Gold Coast 2022 'City Vision'.*
- ***Linear transport corridor:*** *Establishment of a strong 'linear' city transport corridor following the coast, particularly from Southport to Burleigh Heads.*
- ***Transport markets and destinations:*** *Links local precincts to the CBD, and supports multiple transport markets and destinations, including connections to hospital and university precincts. This also includes connections to special events (e.g. Commonwealth Games facilities) and existing tourist attractions that follow the linear city overlay along the coast.*
- ***Public transport perception:*** *'Step change' in quality and attractiveness of public transport (e.g. taking back road space to create light rail).*
- ***Networking integration:*** *Links to intra-regional public transport, including heavy rail at Helensvale.*
- ***Funding and financing:*** *Tri-partite partnering and funding contributions from Federal, state and local governments.*
- ***Benefits realisation:*** *'Building our City – Light Rail Corridor' is a bi-annual assessment and quantification identifying the 'flow-on' economic, social and environmental benefits in proximity of the light rail route. The key measures relate to place, prosperity and people. The key measures indicate that there has been significant year-on-year patronage growth, the number of vehicles at the measured sites continues to decrease, additional active frontages have been created throughout the study area, significant number of development approvals etc.*
- ***Innovative:*** *It was the first light rail network in the world to include surfboard racks, highlighting how the project considered the local context and the passengers that would be using the network.*

The success of the early stages of GCLR has provided momentum for the planning and implementation of subsequent expansion stages, and consideration of an extension into northern NSW. It is also considered a 'catalyst' for consideration of light rail on the Sunshine Coast.

Practical Example:
Sunshine Coast Mass Transit Project, Queensland

Sunshine Coast Council commenced investigations of light rail in 2011. In May 2019, the State Government and Sunshine Coast Council announced a planning partnership to develop an integrated public transport plan for rail, light rail and bus services. A mass transit options analysis, including community consultation, is currently underway, with a detailed business case expected to commence in mid-2021.

Light rail is a key consideration for Sunshine Coast Council and Transport and Main Roads (TMR) in the development of an integrated, multi-modal mass transit network on the Sunshine Coast.

Source: [61]

[53] The announcement of Stage 3 funding of $709m (funded by Australian and Queensland Governments, and City of Gold Coast) was made in November 2019.
[54] City of Gold Coast, Gold Coast Light Rail, https://www.goldcoast.qld.gov.au/gold-coast-light-rail-53512.html, accessed 28/01/21.
[55] City of Gold Coast, Gold Coast Light Rail, https://www.goldcoast.qld.gov.au/gold-coast-light-rail-53512.html, accessed 12/10/20.
[56] RidetheG, G:link, https://ridetheg.com.au/, accessed 12/10/20.
[57] City of Gold Coast, 2020, Building Our City, Light Rail Corridor 2019 Status Report, https://www.goldcoast.qld.gov.au/documents/bf/light-rail-status-report-2019.pdf.
[58] The Conversation, 2017, Why Gold Coast light rail was worth it (it's about more than patronage), https://theconversation.com/why-gold-coast-light-rail-was-worth-it-its-about-more-than-patronage-78190, accessed 13/01/21.
[59] City of Gold Coast, 2019, Building Our City - Light Rail Corridor 2019 Status Report, https://www.goldcoast.qld.gov.au/documents/bf/light-rail-status-report-2019.pdf, accessed 13/01/21.
[60] Damien Haas, 2015, Capital Metro can repeat the Gold Coast's light rail success, https://the-riotact.com/capital-metro-can-repeat-the-gold-coasts-light-rail-success/149038, accessed 22/01/21.
[61] Sunshine Coast Council, 2020, Sunshine Coast Mass Transit project, https://www.sunshinecoast.qld.gov.au/Council/Planning-and-Projects/Major-Regional-Projects/Sunshine-Coast-Mass-Transit-Project, accessed 22/10/20.

A 1.1 Gold Coast Light Rail

The longer term legacy that the project will leave on the city is likely to involve a combination of the following:

- ***City revitalisation:*** *Revitalisation of the Gold Coast CBD and Southport areas.*
- ***Alignment to transport strategies:*** *Provides the north-south 'spine' of the network, supporting future development to further enhance connectivity, including north-south extensions and east-west routes as envisaged in the Gold Coast City Transport Strategy 2031.*
- ***Supporting integrated public transport:*** *Backbone of an integrated high frequency public transport network, including heavy rail and high-frequency bus services. 'Building our City – Light Rail Corridor 2019 Status Report' identified the following:*
    - *Average daily boardings at Southport station increased from approximately 2,200 in 2014/15 to 3,100 in 2018/19 (36.5% increase).*
    - *Traffic decreased by 47% on Scarborough Street (between Young Street and Short Street) from approximately 10,800 in 2011/12 to 5,700 in 2018/19.*
- ***Value uplift:*** *Land value prices in the catchment areas increased in the earliest planning phases. Total value gains to nearby landowners are estimated to be around $300 million, or around 25% of the capital cost of the project [62].*
- ***Increased public transport use:*** *Since the light rail's commencement in 2014, overall public transport use in the area has increased by more than 25 per cent [63].*
- ***Activating streetscapes:*** *Regular surveys of residential and commercial building 'edges', how they 'front' or 'hit the street' close to centres of activity have been undertaken in the light rail corridor. Since 2013, almost 2km of additional active frontages have been created throughout the study area, predominantly through the construction of new building and renovation of old buildings, and mostly through the conversion of previously 'inactive' frontages. An 'active' edge is defined as offering 2-way visual and physical permeability at street level, with activities in these buildings adding a sense of life and activity to the streetscape. The key centres of Southport (18% increase), Surfers Paradise (10%) and Broadbeach (23%) have experienced the biggest changes in active edges.*

A 1.2 CBD & South East Light Rail

With an extra 1.3 million new people expected to live and work in Sydney by 2030 , the CBD and South East Light Rail (CSELR), Australia's newest light rail system, forms a critical part of the city's transport future and urban renewal. The 12km light rail system provides reliable transport between key destinations, to support a vibrant and connected inner city.

Running through the city's heart from Circular Quay to Central Station, the new line continues past two high schools towards major sporting and entertainment facilities at Moore Park, including the Sydney Cricket Ground (refer to Figure 8).

It then diverges into the following lines:

- ***R2 Randwick Line :*** *connecting Centennial Park, Randwick Racecourse, Randwick TAFE College, the University of NSW and the Prince of Wales Hospital.*
- ***L3 Kingsford Line :*** *connecting Kingsford past the ES Marks Athletics Field and the National Institute of Dramatic Art.*

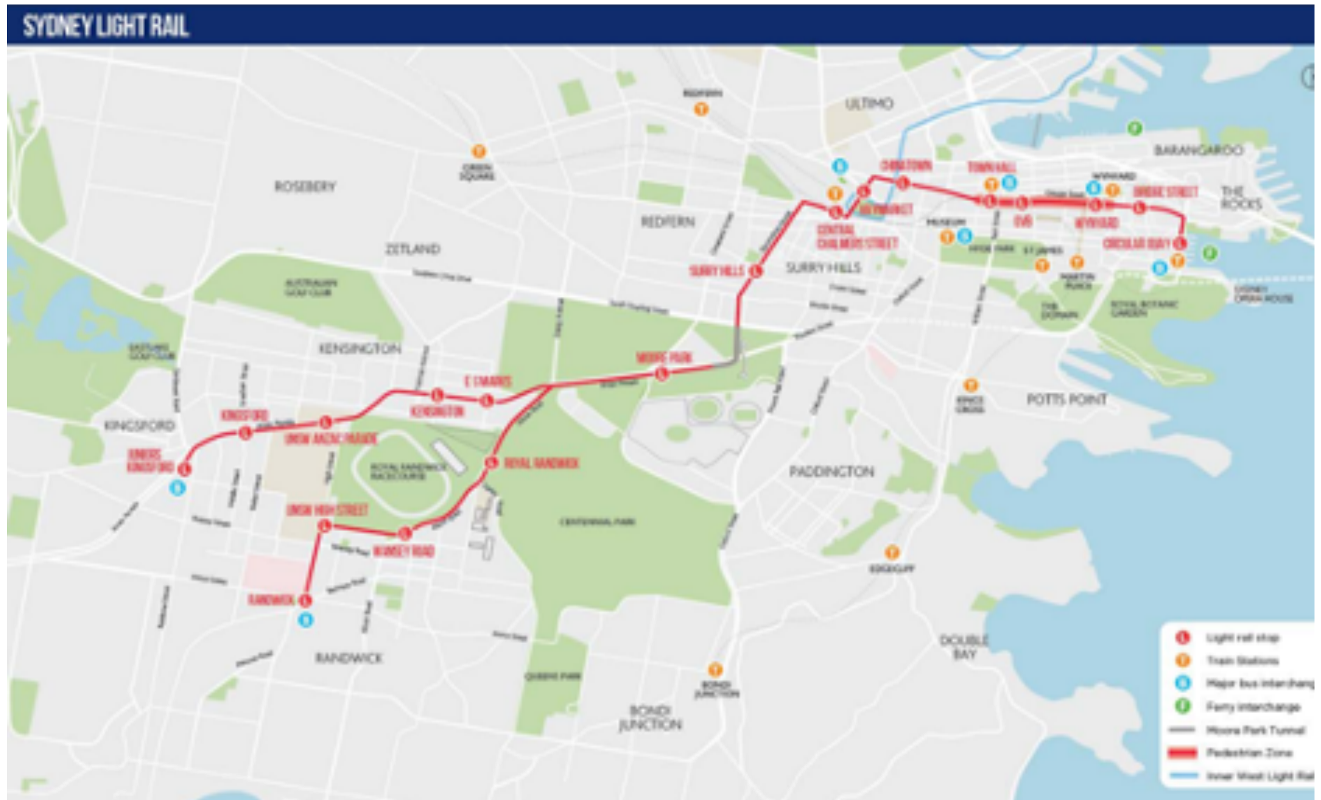


Figure 8: Sydney CBD and South East Light Rail Route Alignment Map [65]

[62] Murray, Cameron, Land Value Uplift from Light Rail (September 5, 2016). Available at SSRN: https://ssrn.com/abstract=2834855 or http://dx.doi.org/10.2139/ssrn.2834855.
[63] City of Gold Coast, 2018, Public Transport Plan 2018–2028 – Delivering the next generation of public transport, https://www.goldcoast.qld.gov.au/documents/ps/public-transport-plan-2018-2028.PDF.
[64] The Sydney Morning Herald, 2019, Sydney's moment of truth, https://www.smh.com.au/interactive/2019/sydney2030/population/#:~:text=Of%20the%20near%2D1.3%20million,rich%20areas%20and%20poor%20areas., accessed 30/11/20.
[65] NSW Government, 2018, CBD & South East Light Rail, https://mysydneycbd.nsw.gov.au/projects/cbd-and-south-east-light-rail,accessed 27/10/20.

A 1.2 CBD & South East Light Rail

General Characteristics		
Operation 14 December 2019 (L2 Randwick) 3 April 2020 (L3 Kingsford)	**Total Distance** 12 km	**Average Speed** 20 km/hr
Operator Transdev	**No. Stations** 19	**Top Speed** 70 km/hr
Construction Cost $3.1 billion Funded by NSW Government and City of Sydney Council	**Patronage** Over 1 million passengers per month Year 1 (2020): >8.5 million	
Original Drivers		
Strategic drivers Alignment to key strategies including the NSW Long Term Transport Master Plan, Sydney's Light Rail Future, Sydney City Centre Access Strategy, Draft Metropolitan Strategy for Sydney to 2031 and NSW 2021: A Plan to Make NSW Number One.	**Public realm** Increase in local amenity and productivity while reducing traffic congestion and environmental health impacts by establishing a metropolitan inspired public realm space along George Street (e.g. pedestrianisation from Circular Quay through to Haymarket).	
Future proofing the network Addressing network capacity issues and existing constraints to support increased patronage and predicted future growth along the corridor.	**Network connectivity** Improve public transport access and unreliable journey times between the CBD and Kingsford health precincts in Randwick, University of NSW, TAFE and major sporting and entertainment facilities at Moore Park. Furthermore,	

Table 3: Case Study – CBD & South East Light Rail [66,67,68,69,70]

Driven by the light rail's success, a greater emphasis by the NSW Government has been put on place-making and the creation of more shared spaces across the Sydney CBD, like that shown in Figure 9. Future investment is likely to occur at the following destinations:

- ***George Street**: The permanent pedestrian zone on George Street in Sydney's city centre is set to be extended further south for another kilometre. This project will increase the pedestrianised section of George Street from one to two kilometres in length, supporting the City of Sydney Council's long term plan to link public squares at Circular Quay, Town Hall and Central Station via a "civic spine" to improve the CBD's public realm* [74].
- ***Oxford Street:** There is a push to inject more life into the area through reducing vehicle speed limits, establishing new bike paths, while ultimately providing a more connected and enjoyable experience for the community and tourists alike* [75].

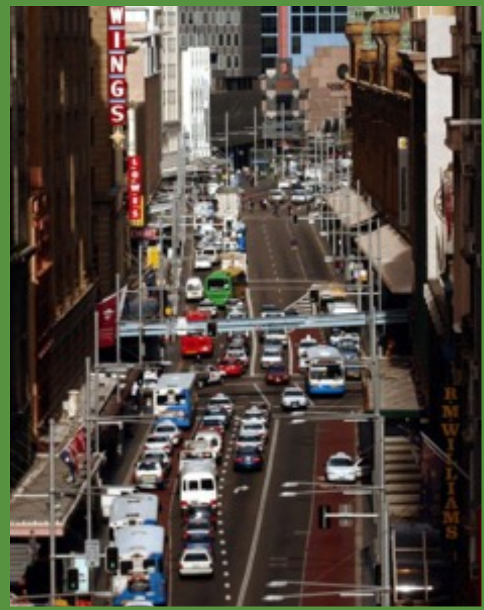
The success of the project has been driven by the following factors:

- ***Linear transport corridor:** Establishment of a strong 'linear' transport corridor along George Street through the city's central core.*
- ***Network integration:** Links to inter-regional and intra-regional public transport (at key destinations including Central, Randwick).*
- ***Transport markets and destinations:** Supports the connection of key destinations including entertainment, health and university precincts.*
- ***Alternate transport option:** Although there were some issues with travel times along the route* [76]*, the light rail provides a reliable form of public transport connecting Kingsford and Randwick to the city and vice-versa (i.e. consistent time from boarding to destination) that the existing bus network cannot deliver.*

It is acknowledged that the project has had to overcome significant challenges, most considerable of which occurred during the construction phase (refer to the case study outlined in section 3.2 previously). However, moving forward, CBD&SE light rail is anticipated to have the following long lasting legacies on Sydney:

- ***City place-making:** Fastrack of greater place-making outcomes (e.g. al fresco dining areas) and pedestrianisation in the city to improve urban liveability through creating desirable shared spaces along the alignment.*
- ***Tourist drawcard:** Highlighting Sydney as a global cosmopolitan centre, ending the journey at the city's crowning jewels, the Sydney Harbour Bridge and the Opera House at Circular Quay*

Figure 9 below highlights the dramatic change to the streetscape along George Street, Sydney as a result of the CSELR. Both photos are taken at the intersection of George St and King St, looking south towards Town Hall Station.



Pre CSELR (2010) [72]

Post CSELR (2019) [73]

Figure 9: George Street Before and After the CSELR

[66] TfNSW, 2020, CBD and South East Light Rail, https://www.transport.nsw.gov.au/projects/current-projects/cbd-and-south-east-light-rail, accessed 04/12/20.
[67] TfNSW, 2013, CBD and South East Light Rail – Business Case Summary, http://data.sydneylightrail.transport.nsw.gov.au/s3fs-public/CBD%20AND%20SOUTH%20EAST%20LIGHT%20RAIL%20%E2%80%93%20BUSINESS%20CASE%20SUMMARY.pdf, accessed 04/12/20.
[68] Rail Express, 2020, Auditor-General calculates cost of Sydney light rail at $3.1bn, https://www.railexpress.com.au/auditor-general-calculates-cost-of-sydney-light-rail-at-3-1bn/#:~:text=The%20final%20cost%20of%20the,was%20announced%20in%20November%202019., accessed 04/12/20.
[69] Sydney Morning Herald, 2020, Vague and half-baked: Lagging CBD light rail set to speed up.
[70] Transport for NSW, 2021, Light rail Patronage, https://www.transport.nsw.gov.au/data-and-research/passenger-travel/light-rail-patronage, accessed 28/01/21.
[71] L3 Kingsford Line started operations in April 2020 and the patronage numbers were recorded during the Covid-19 pandemic.
[72] Sydney Architecture Archive, 2010, By George, this blight has to stop, for Sydney's sake, https://sydneyarchitecturearchive.wordpress.com/2010/01/20/by-george-this-blight-has-to-stop-for-sydneys-sake/, accessed 08/12/20.
[73] Broadsheet, 2019, How To Ride Sydney's New Light Rail Like A Pro, https://www.broadsheet.com.au/sydney/city-file/article/how-ride-sydneys-new-light-rail-pro, accessed 08/12/20.
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A 1.3 Parramatta Light Rail Stage 1

RPS has used hedonic regression to assess the potential value uplift along the PLR corridor. This approach uses regression techniques that account for local factors such as surrounding development typology, lot size, number of dwellings and distances to key points of interest (e.g., Parramatta CBD, proposed light rail station, etc.).

Based on this modelling, presents a hypothetical redevelopment of a low-density residential dwelling approximately 250 metres from the proposed light rail station. This example is indicative to provide a sense of magnitude of the uplift that can occur locally through densified additional dwellings along key strategic corridors.

	Area (m^2)	No. Hypothetical Units	Value/m^2	% Uplift
Low Density	725	1	1,341	--
To Medium Density	1,415	15	1,369	2.1%
To High Density	2,175	30	1,538	14.7%

Table 4: PLRS1 percentage uplift analysis

To inform our modelling, RPS first assessed the near-term impacts of PLR Stage 1 (refer to Section 3.1 previously). In undertaking this analysis, we conducted spatial analysis of property values along the PLR corridor and then estimated a hedonic regression. The first approach does not correct for other factors that may have impacted property values over the same time period while the second approach includes variables for other factors that may impact property values including proximity to the Parramatta CBD, the type of zoning, proximity to green space, proximity to water etc.

Based on the spatial analysis undertaken, we applied our hedonic regression modelling to assess potential uplift of additional density. Figure 10 illustrates the modelled uplift resulting from additional densification, noting that it presents only coefficients for the density variable from the model. The modelling suggests that it would be reasonable expect that higher densities would drive disproportionately higher land values to the north west along the PLR corridor. Given the current housing typology this is a likely outcome, subject to coordinated and integrated land use and transport planning.

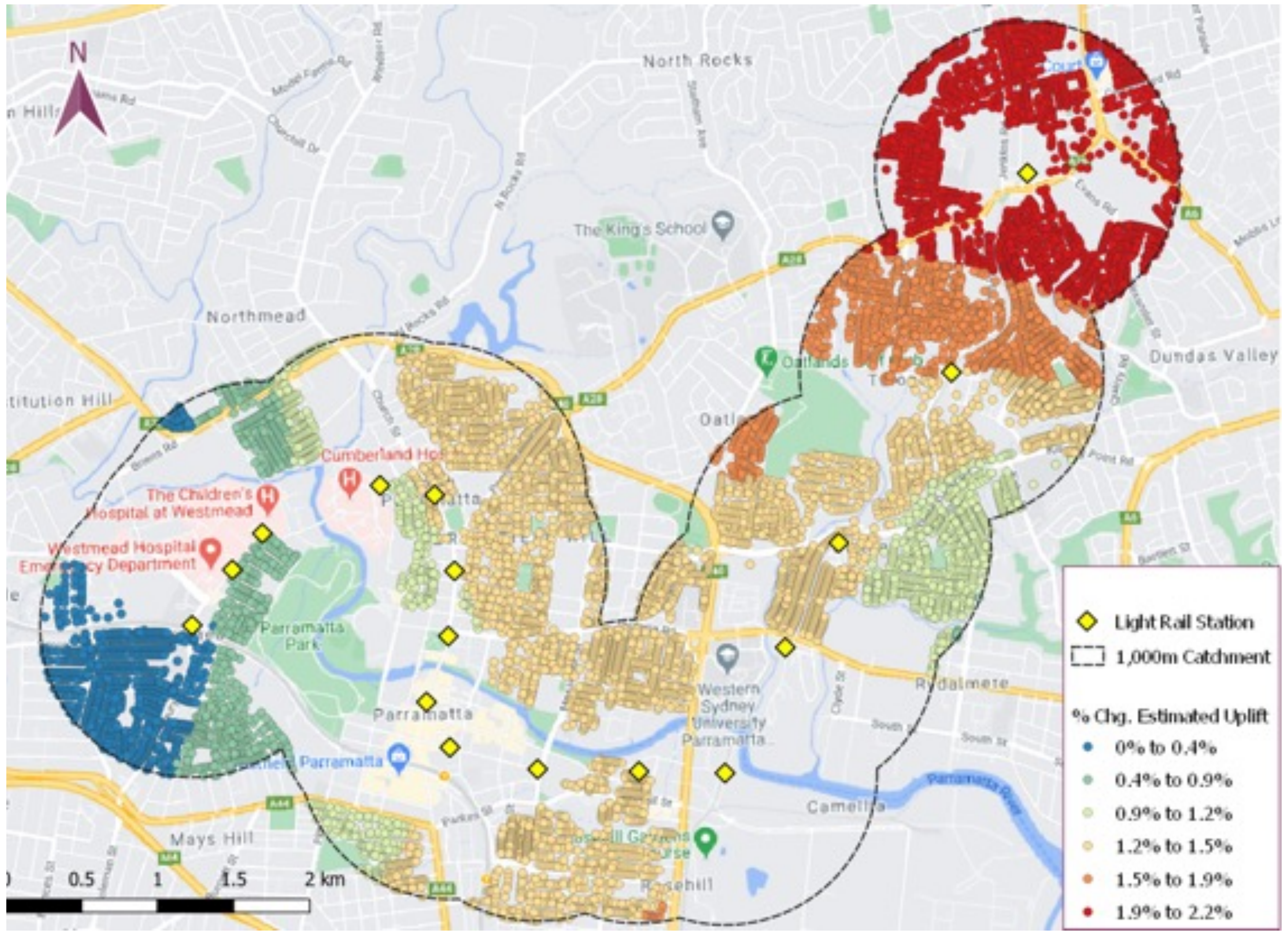

Figure 10: Modelled Percent Uplift from Additional Density (R2, R3 & R4 zones, per Additional Dwellings)

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